Effects of assistive technology for students with reading and writing disabilities

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Effects of assistive technology for students with reading and writing disabilities

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ABSTRACT

Background: Assistive technology has been used to mitigate reading disabilities for almost three decades, and tablets with text-to-speech and speech-to-text apps have been introduced in recent years to scaffold reading and writing. Few scientifically rigorous studies, however, have investigated the benefits of this technology.
Purpose: The aim was to explore the effects of assistive technology for students with severe reading disabilities.
Method: This study included 149 participants. The intervention group received 24 sessions of assistive technology training, and the control group received treatment as usual.
Results: Both the intervention and control groups improved as much in 1 year as the normed population did. However, gains did not differ between the groups directly after the intervention or at 1 year of follow-up.
Conclusions: The use of assistive technology seems to have transfer effects on reading ability and to be supportive, especially for students with the most severe difficulties. In addition, it increases motivation for overall schoolwork. Our experience also highlights the obstacles involved in measuring the ability to assimilate and communicate text.

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Reading and writing disability; assistive technology; apps; interventions

➤ IMPLICATIONS FOR REHABILITATIONS

- Assistive technology (AT) can be useful for children with reading disabilities to assimilating text as well as boosting their reading.
- Children with reading disability using AT increased reading performance as much as a norm group, i.e. the students enhanced their reading ability despite no training in traditional reading remediation.
- Children's and adolescents' motivation for schoolwork can be boosted when using AT as a complement for those with reading and writing disabilities.

Introduction

Reading and writing at a relatively high level are required to ensure competitive participation in society. However, ~20% of the school population has some kind of reading difficulty, including about 5–8% of the global population with dyslexia [1,2]. An abundance of research has shown that training focused on phonological ability benefits students with severe reading difficulties [3,4]. Among those with severe reading and writing disability (e.g. dyslexia), however, even intensive training might be insufficient to fully remediate their difficulties and bring them to an adequate level of reading and writing. For these learners, simply 'trying harder' [5,6] is not enough, and 'more of the same' training risks that the gap between their reading and writing skills and school requirements will increase over time. The most common way to ameliorate reading and writing difficulties is to use targeted exercises, such as practicing the relation between letter and sounds, that train students to become better readers [2,4]. A second option is to try to compensate for the difficulties by using assistive technology, for example, listening to text instead of reading, that is, a workaround of the problem (cf. eyeglasses to compensate for a loss of vision) [7,8]. The present study explored the use of assistive technology as a complement to reading and writing the traditional way.

Assistive technology has been used for decades to support students with reading and writing disabilities, as well as for other disabilities. One definition of assistive technology is presented by the International Organization for Standardization [9]:

> An assistive product is any product (including devices, equipment, instruments and software), especially produced or generally available, used by or for persons with disability, for participation, to protect, support, train, measure or substitute for both functions/structures and activities, or to prevent impairments, activity limitations or participation restrictions.

In recent decades, the equipment and programs/applications (apps) for supporting reading and writing have also been available for tablets and smartphones, which has improved accessibility even more than computers have [10,11]. Apps that

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compensate for impaired decoding and writing abilities, such as text-to-speak (TTS) and speech recognition/speech-to-text (STT), are particularly suitable as supplements for these skills. These apps could thus be regarded as an alternative to the traditional way of reading and writing, especially for students with severe disabilities related to these skills [12]. In practice, this means that people with such difficulties have constant access to tools via tablets and their applications which support the ability to assimilate and communicate text and thus might increase the opportunity to feel independent and be able to participate in the societal process on equal terms. Assimilating and communicating text are broader concepts which implicate that these tools will allow individuals to take part of all kinds of information by conveying their own thoughts and ideas, even if they have great difficulties in reading and writing the traditional way [8,12]. The general attitude among teachers and those who work with students that have these difficulties is that assistive technology such as TTS and STT is of great help [13]. Students will not only become better at assimilating and communicating text, but their motivation for using the written language will also increase, which may in turn improve students' self-image when it comes to school-work in general [12,14]. In a study by Furió, Juan, Seguí and Vivó [15], the authors proclaim that a smartphone is at least as well suited for some parts of a classroom lesson regarding learning and motivating children. Children of the present generation are familiar with technical equipment, such as mobile devices, and therefore feel more comfortable when using this in comparison to traditional methods used in classroom settings [15].

Nevertheless, so far, a fairly limited number of publications are available which provide evidence that students with reading and writing disabilities who use assistive technology become better readers and writers [2]. In a recent review by Perelmutter, McGregor and Gordon [16], the authors came to the same conclusion, that is, that research is limited concerning learning disabilities (LD) and assistive technology, especially research with a sufficiently high scientific or 'Gold' standard. Still, a majority of the studies that the authors included in their review [16] showed to be overall beneficical when using assistive technology for adolescents and adults with LD. Interventions based on word-processing, multimedia and hypertext seem to be the most effective, while TTS and STT showed more mixed results. The authors concluded that assistive technology has to be customized to the individual to be effective. However, most of the studies using TTS and STT are quite old, and the technology has changed and advanced since their publication. Thus, current technology is more reliable regarding voice quality and speech recognition. Furthermore, TTS and STT are often included as an option in new smartphones and tablets [14].

Other international studies [7,17,18] highlight the benefits of using alternative tools as well as the risks of persisting too long with practicing abilities that students have not mastered despite training; for example, those with severe reading difficulties. '*If a child repeatedly fails to read and to understand printed text, how much data documenting this failure needs to be gathered before we have enough evidence that the child cannot perform the task?*" [5]. Most relevant research has aimed at investigating various programs used in computers to scaffold the different abilities related to reading and writing. Because apps on tablets or smartphones have been available only for 10–11 years, however, research has been fairly limited. The benefit of such apps is their accessibility and the reduced risk of associated stigma, which earlier studies have reported [16,19]. In the review by Perelmutter et al. [16], only a study conducted by authors [20] used apps on a smartphone or tablet in connection with TTS or STT. In that investigation, the students used a multifunctional app (Prizmo) in a tablet to scan texts from a book or newspaper and then make the text listenable via TTS. The authors concluded that a multifunctional app might be beneficial for decoding ability as well as motivation for future studies. Other recent studies have also emphasized the benefit of using TTS for struggling readers, especially from a student perspective, for example, accessability to text and confidence in the classroom setting [21–25]. In a pilot study [12], 35 students aged 10–12 years with documented reading and writing difficulties (of which 30% diagnosed were with dyslexia) participated. The study aim was, among other things, to investigate the transfer effect on reading ability when using assistive technology systematically. The students used different kinds of apps in tablets like TTS, STT, Prizmo (scanner and TTS), or Pages (word processor). They received 20 sessions of systematic training with these apps for 6 weeks. The results suggested that assistive technology can create a transfer effect on reading ability, that is, increasing decoding ability and decreasing the gap to non-impaired readers. In addition, the authors discussed the need to challenge the concept of reading to fit modern means of accessibility to text, that is, to assimilate (i.e., read) and communicate (i.e., write) text. Students, parents, and teachers in the study also reported increased school motivation and independent learning [12].

These studies still have obvious limitations, such as including few participants, measuring only decoding aspects, or lacking a comparison group. Earlier publications have also pinpointed some difficulties in measuring aspects of reading after using assistive technology [8,12,14]. Thus, because the main aim of assistive technology is to compensate for a particular shortcoming, a positive effect on the reduced ability, for example, reading, is not self-evident. The students might become better at assimilating and communicating text, the overall goal of reading and writing, but not at using a traditional reading or writing method. Consequently, the method of measuring abilities to assimilate and communicate text is not obvious, at least not in the short-term perspective.

In their review, although Perelmutter et al. [16] found that the studies tended to report positive results with devices such as TTS and STT, they recommended more rigorous research into these tools. These authors identified gaps requiring further research, such as the type, frequency, and purpose of assistive technology and the satisfaction resulting from it.

The recent reviews in the area claim that most published studies are now fairly old and do not incorporate the latest developments within assistive technology. The authors advocate more comprehensive, systematic, longitudinal, and in-depth investigations [14,16].

In this study we present data from three test occasions, documenting the effects of a 6-week intervention that incorporated a variety of available assistive technologies on a battery of reading skills and on reports from students and parents about the functionality and usefulness of the apps during the school day. The overall goal of our study was to obtain a deeper understanding of the lived experience related to using assistive technologies in and out of the classroom environment to support improvement in students' reading and ability to assimilate and communicate text.

Aims and research questions

The first aim of this study was to investigate whether a systematic use of various assistive technologies has any effect on traditional reading ability. Using assistive technology can be viewed as a way to assimilate text without having to rely on, for example, word decoding; thus, a tradeoff is possible between training and

Table 1. Number of participants allocated for test occasion one (T1) divided by grade and sex.

	Control/Intervention		
$N = 149$	Grade 4	Grade 8	High school
Female	17/19	4/7	2/4
Male	30/30	14/11	4/7
Total	47/49	18/18	6/11

Table 2. Schedule of the intervention process and distribution of participants on each test occasion.

	Intervention	Control
Screening	$n = 78$	n=71
	Treatment as usual (TaU) 4 weeks	
Start test (T1)	$n = 77$	$n = 66$
	Intervention 8 weeks	*TaU 8 weeks*
Post test (T2)	$n = 68$	$n = 60$
	TaU 1 year	
Follow-up test (T3)	$n = 55$	$n = 49$

compensation/alternative routes to text comprehension, so that control students receiving regular reading instruction might improve their reading skills more than the assistive technology group. It is also possible, however, that assistive technology will lead to more meaningful exposure to text, new knowledge, and positive indirect effects on basic reading skills and thus, develop reading skills almost as much with assistive technology as they do with ordinary reading instruction [12,16].

A second aim was to explore the ability to assimilate and communicate text among students with documented reading and writing disabilities. For the second aim, a plausible assumption is that the students will increase their ability to assimilate and communicate text.

A third aim was to analyze how the students and their parents have experienced the tablet with apps and whether the use of assistive technology affects student motivation to achieve literacy and for overall schoolwork. With regard to the third aim, we sought responses to targeted questions about how students and parents perceived the use of assistive technology and whether the students still used the technology after the interventions. The intention was to determine whether assistive technology affected everyday schoolwork in reading and writing and/or in assimilating and communicating text as well as student motivation for schoolwork in general.

Research questions

1. Were there any differences between the experimental group receiving assistive technology; (a) a control group receiving treatment as usual in terms of gains in reading skills? (b) to an age-matched norm group?
2. Did the experimental group gain in ability to assimilate and communicate text when using assistive technology?
3. Has the assistive technology intervention affected student motivation for reading tasks and schoolwork in general?

Method

In the present study, students from middle to high school were included. The main reason for this choice was to include students who, despite at least 3 years of traditional education and special education approaches in the Swedish language, still had profound reading difficulties. Furthermore, students needed to be old enough to manage and be responsible for the technical equipment used in the study. Consequently, samples were gathered from grades 4 and 8 as well as from high school with the aim of investigating differences in the use of assistive technology from one grade to another. However, because the number of participants was low in grade 8 and in high school, in particular, statistical analyses across the grades was not tenable.

Participants

The present study included 149 (53 girls, 96 boys) participants distributed among grades 4 and 8 in lower and middle school and year one in high school (Table 1). We planned to include 60 participants from each grade, 30 in the intervention group and 30 in the control group, to detect an effect size of 0.5 with a power of 90% in the combined sample. However, for various reasons, as described below, gaining the number of participants intended for grade 8 and high school proved difficult.

Students and teachers were selected from various schools representing both rural and urban locations in the southern part of Sweden. In total, 60 schools and 70 teachers were involved in the intervention. Because students with severe impairments in reading are scarce, a large number of schools and teachers was needed. Those that performed within or below the tenth percentile on decoding after they had carried out two decoding tests (non-word reading and sight-word reading) were eligible. This threshold was used in earlier research examining students with severe reading difficulties and dyslexia [2,26]. In addition, students had to have documented difficulties in reading and writing. Students with other difficulties, such as language impairment and autism spectrum disorder, were excluded, as were those who had not attended Swedish school from grade 1.

Students eligible for the study were allocated to control or intervention using the following procedure separately for each grade. First the two screening tests 'LäSt non-word reading' and 'LäSt sight-word reading' were normalized to Z-scores. Then all possible allocations into two groups were evaluated using the following constraints: (1) Teachers with more than one student were guaranteed to have at least one student in the intervention, and (2) the two sexes were allocated as evenly as possible. The allocation that conformed to these two constraints and had the smallest Euclidean distance between the group means of the two Z-scores was used. The experimental group received the assistive technology interventions, and the control group received treatment as usual, as described below in the 'intervention procedure' section.

To increase motivation to participate and prevent possible dropouts in the control group, participants were also offered use of assistive technology devices after the follow-up, that is, 1 year after interventions ended. However, dropouts ($n = 6$) still occurred in the high school control group even before the intervention period began, primarily because they did not want to wait 1 year before using the same equipment and apps as the intervention group. Consequently, the dropouts were not linked to student achievement during the intervention. Thus, 143 students participated at T1, just before the intervention. After the intervention was completed (T2), an additional 15 students did not complete the test battery. Except for the above reason, the attrition was due to students and teachers moving to another school or to reports from the school that the staff did not have time to carry out the interventions or the test battery. Finally, at follow-up (T3, 1 year later), there were 24 more dropouts, citing the same reason as noted above. In total, 104 students participated at T3 (Table 2), for an attrition rate of 30%. There were no significant differences on the reading tests between the dropouts ($n = 45$) at T1 and the students who completed T3.

Table 3. Complete list of tests used in the study.

Area and test	Test details	Psychometrics	Reference
Word decoding/recognition			
Wordchains test	Silent reading and separation of three unrelated real words presented in chains during 120 s. Correct separation was registered.	Test-retest reliability = 0.92	[33]
Sight-word reading A	Correctly read aloud words were registered. 45 s	Test–retest reliability = 0.97	[34]
Non-word reading B	Correctly read aloud non-words were registered. 45 s. A + B were aggregated into a total score.	Test–retest reliability = 0.97	[34]
Orthographic choice	130 real words paired with pseudo-homophones (e.g., game-gaim). Identification of correctly spelled words were registered. 120 s.	Norms for grades 3–9 were available	[35]
Short-term memory and fluency			
Non-word repetition	Correct repetition of 16 orally presented non-words were registered.	Comparison data from grade 2–9 were available	[3]
Rapid automatized naming (RAN)	Total time for reproducing 70 items (digits 1–5) were registered.	Comparison data from grade 6 were available	[3]
Reading comprehension			
Which Picture Is the Correct One? (Grade 4 only)	Correct discrimination of four pictures related to two or three sentences were registered. 5 min.	Norms were available	[36]
IEA: International Association for the Evaluation of Educational Achievement (Grade 4 only)	Correct answers of 12 questions related to two texts were registered.		
Text from the National test in Swedish (Grade 8 and high school only)	Correct answers of 11 questions related to an authentic text were registered.		
Sentence chains	Silent reading and separation of four unrelated sentences written together. Correct separation was registered.	Test–retest reliability = 0.80	[33]
ITPA: Sentence sequence (Grade 8 and high school only)	Logical reorganization of a set of sentences were registered.	Norms were available	Illinois Test of Psycholinguistic Abilities
ITPA: Vocabulary	Semantically correct associations from a sentence (e.g., "I'm thinking of something that has a button" – "a jacket") were registered.	Norms were available	Illinois Test of Psycholinguistic Abilities
ITPA: Written words	Semantically correct associations between an adjective (e.g., "a fun") and a noun ("movie") was registered.	Norms were available	Illinois Test of Psycholinguistic Abilities
Listening comprehension			
Subtest from Woodcock Reading Mastery Tests	While listening to orally presented sentences, correct identification of "missing" words were registered. The level of difficulty increased with number of words.		[37]
Arithmetic ability			
Test of arithmetic ability	Correctly solved 60 simple addition and subtraction items (e.g., 9–2) were used as a measure of arithmetic ability during 60 s.		
Assistive technology usage			
Reading and listening comprehension	A test measuring the difference between unassisted and assisted (TTS) reading. Two texts (with 5 questions to each text) for each condition were used, with random allocation to start with either the unassisted or the assisted reading condition.		Standardized texts from the IReST-project [38]

The present study received ethical approval (reference number 2014/253–32) from the Ethic Review Board in Linköping Sweden (EPN).

Test procedure

All reading tests were administered by a teacher who did not deliver the interventions. Teachers administering the test battery received training for each test, and most of them were special education teachers with many years of experience in administering reading and writing tests. The pre-testing of the students, which occurred 4 weeks before the interventions, included three tests: word recognition, sight-word reading, and non-word reading (see 'Participants' section for eligibility).

At T1, the test battery was more comprehensive. In addition to the test described above, tests were used to measure reading comprehension, listening comprehension, vocabulary, fluency, and short-term memory. A further intention behind some of the tests in T1 (listening comprehension and vocabulary) was to estimate student ability to assimilate and communicate text, that is, not only to measure traditional reading and writing ability. Questions also were included about their current reading and writing ability. In addition, tests of self-image, psychological well-being, and teacher perceptions of the use of the apps in the study were conducted (results to be published elsewhere). The time for administering the test battery was ∼60–80 min on all test occasions, except for the screening procedure. Teachers who conducted the interventions also reported each week about the work they had carried out with the students. The same information was also gathered for the control group receiving treatment as usual (see 'intervention procedure' below). Unfortunately, the reporting from teachers was not as structured for this group.

Immediately after the intervention period ended, the next test occasion (T2) took place. The same test battery as T1 was administered except for one of the reading comprehension tests in grade 8 and high school. Because the aim was to avoid the test–retest effect, this testing was conducted again only at the follow-up. In addition, at T2, the intervention group completed a test measuring differences in reading and listening to a text, the time, and correct answers to questions (see the description of the reading and listening comprehension test below). The students in the intervention group and their parents answered questions about how they had understood the interventions and the tablet with apps as well as questions about motivation.

At the follow-up (T3), students completed the same tests and questions again, but this time, parents also answered questions regarding their perception of their child's participation in the study (in the intervention group only). In addition, we wanted to examine whether the participants had decided to continue to use assistive technology after the intervention period, which signals generally perceived usefulness of the different applications. Other researchers have used concepts like social validity, clinical significance, or lived experience as important outcomes to express individual satisfaction with an intervention, in this case the use of assistive technology [16,27,28]. For an overview of the test occasions, intervention periods, and participating students, see Table 2.

Materials

The assessment battery for this study has been commonly used for investigations of reading and writing disabilities and dyslexia in an international perspective, as well as in Sweden [12,29–32]. See Table 3 regarding the included testbattery.

A battery of questions were also included. Students and their parents answered questions concerning the use of apps, for example, "*How often do you use the apps that were included in the project today?*", "*Do you follow the teaching better today when using apps?*", and "*Has your motivation for schoolwork increased after working with reading apps?* The questions had five choices, two positive and one neutral, and two negative options. Furthermore, there were also open-ended questions such as, "*How well did it work to use the tablets?*" and "*Which of the following programs (apps) did you benefit most from?*" (the student had to rank a maximum of two programs.). The questions were administered immediately after the students had finished the intervention and at the follow-up. For most of the students in grade 4, the teacher who conducted the tests read the questions aloud. Students in grade 8 and in high school had mostly read and answered the questions themselves. For a complete list of questions see Appendix.

Applications

We selected applications that are commonly used in Sweden, some of which were not exclusively designed for education and some that were. The applications were selected based on their features and their usability for scaffolding reading and writing and for schoolwork. The selection was carried out in consultation with members from the National Agency for Special Needs Education and Schools. Furthermore, in an earlier pilot study [12], we evaluated several of the apps used in this study. From the experience of that study, we knew that the apps worked in a pedagogical setting. They include features such as spoken text (which also provides the ability to choose a preferred voice, dialect, and speed); dictating speech-to-text (speech recognition); the ability to copy, paste, and edit a text, following along in a text as words are being read; receiving direct voice feedback of the text being produced; and creating bookmarks as well as taking notes. The applications were also mutually compatible. The applications we used were SayHi (speech-to-text = STT), VoiceDreamReader (text-to-speech = TTS), Prizmo (scanning from written text to digitalized text), Skolstil-2 (an easy word processor and text-to-speech app that even pronounces each sound-letter, words, sentences, and the whole text while writing a text), Legimus (an audiobook reader), and Ruzzle (a word game). All applications were used in tablets.

Intervention procedure

Between the screening procedure and T1 (4 weeks), the students eligible for participation received typical reading and writing instructions such as the relation between letter and sound and reading comprehension exercises. In most cases, two teachers participated in each school, one teacher carrying out the tests and the other conducting the interventions. During this month, the teachers had 2 days of training in how to implement the manual-based interventions and use the tablets with their supplementary apps. They also had access to a website for support and to discuss different issues regarding implementing the interventions with both the project group and their colleagues. Thus, the teachers were to be as prepared as possible before starting the interventions with the students. The intervention comprised 24 one-to-one sessions, 4 sessions each week during 8 weeks with a 1-week pause in the middle (at fall and spring breaks, depending on in which semester the participants took part in the intervention). The sessions ($M = 21$, SD 3.9) lasted ∼30–40 min ($M = 806$, SD 194.3). In addition, the participants also carried out exercises at home (listening to a book via the Legimus app). The length and frequency of the sessions were based on prior research and from the pilot study, which recommended short, regular, and structured sessions instead of longer ones, which would have been too exhaustive for the students [12,39,40]. One of the aims with the interventions was to practice the students' ability to assimilate and communicate text. Therefore, the manual-based interventions included instructions to listen to text via a TTS app, *assimilate* it, and then write down the content of the text in a couple of sentences. They also were allowed to use the STT app to communicate the text content to a word processor instead of writing it down. If students chose to write the sentences in the word processor, the program also offers a spell checker and the possibility to listen to the text they have written to make it as correct as possible. The teacher encouraged the students to question the text before formulating its content via STT or the keyboard. For example, the teacher asked questions via STT, and the students answered via the same application, thus forming an interview with the use of both the tablet and the application. It was then possible to copy these questions and answers into a word processor.

Students could choose between two-word processors: (1) Pages, which accompanies the tablet, or (2) Skolstil-2, a word processor created to suit students with reading and writing difficulties. It is possible for the students to type down the text and then listen to anything from each sound in a word to the whole text, as well as to receive help with spelling. At the end of the week, the students compiled the week's texts and then went through them together with the teacher. As some of the texts that the students listed/read were not digitized, they used a scanner (Prizmo, a tablet app) with an optical character recognition program to do so and thus make the written text available for listening. The students used texts representing the types that they worked with in school in different subjects via texts from a website or texts from books or newspapers. When the students used material that they did not work with in school, they were encouraged to choose other texts of interest to them. The students also received a homework assignment to listen to a fiction book (at a

Table 4. Mean and SD on each test at T1 and T2 for the intervention group and for the control group at grade 4.

Test	Control ($n=42$) T1 mean ± SD	Control T2 mean ± SD	Control Change p	Intervention ($n=44$) T1 mean ± SD	Intervention T2 mean ± SD	Intervention Change p	Intervention vs control Effect size Cohen's d	p
Word chains	8.3 ± 4.6	9.4 ± 4.2	.04	6.9 ± 3.6	8.3 ± 3.9	<.001	0.07	.67
Sentence chains	10.6 ± 5.7	11.0 ± 5.2	.48	8.5 ± 5.2	9.7 ± 4.6	.06	0.14	.41
Non-word reading	45.0 ± 14.6	48.3 ± 16.9	.01	41.9 ± 12.8	45.6 ± 13.2	<.001	0.03	.79
Sight word reading	77.7 ± 24.5	87.2 ± 24.9	<.001	76.0 ± 21.1	84.8 ± 24.0	<.001	−0.03	.81
Orthographic choice	16.7 ± 6.9	20.9 ± 10.0	<.001	14.4 ± 7.9	19.6 ± 9.7	<.001	0.11	.51
RAN	46.1 ± 10.3	43.7 ± 12.2	.02	47.2 ± 13.1	44.6 ± 10.6	.07	−0.02	.90
Non-word repetition	11.6 ± 2.4	13.0 ± 2.2	<.001	11.2 ± 3.5	12.4 ± 3.0	<.001	−0.08	.66
Arithmetic	11.2 ± 5.9	12.2 ± 5.4	.27	9.6 ± 6.0	10.7 ± 6.2	.02	0.02	.88
Correct picture	13.5 ± 4.7	16.6 ± 4.7	<.001	12.1 ± 4.0	15.1 ± 4.2	<.001	−0.03	.83
Vocabulary	14.3 ± 3.6	16.0 ± 3.2	<.001	15.1 ± 3.9	15.9 ± 3.0	.09	−0.27	.22
Woodcock listening	18.3 ± 4.3	21.8 ± 4.4	<.001	19.5 ± 4.1	21.7 ± 3.7	<.001	−0.32	.04

Effect size, Cohen's d, is presented regarding differences in gains between the groups on the tests.

minimum of 10 min, 4 days a week) and then produce a couple of sentences via STT about the content of the part of the book they had listened to. In addition, a word game application (Ruzzle) was used. The task was to find as many words as possible in a square with 16 letters within 2 min. The aim of this game was to maintain motivation and give students a short break from the intervention exercises [15]. In earlier studies by Authors, et al. [3] and Authors [12], they advocated that the sessions should not be too time-consuming and that the exercises should vary. The teachers received a manual-based instruction of how to carry out the interventions. However, because the overall goal was to customize the equipment according to student needs, the instructions offered the opportunity to individualize the issues.

The intervention group obtained no other remediation except using assistive technology during the intervention period. After this, the intervention group students were encouraged to use assistive technology in their schoolwork in general. They also received the usual treatment that they had received before the intervention period. The students in the control group had the kind of training that those with reading and writing difficulties usually receive in Sweden. The tasks they were assigned, according to the teachers' report, included matters like "*special education training two times a week*", "*practicing reading and writing, practicing decoding strategies twice a week*", "*practicing the relation between sound and letter*", "*systematic decoding training for 20 min four times a week*", "*reading a text and then discussing the content of the text with the teacher*", "*oral reading*", "*practicing sentence building in a correct grammar*", and "*practicing reading mathematical tasks*". Thus, the remediation the control group received varied both in kind and in the time the students practiced. Students in the control group were not supposed to use assistive technology during the intervention or during the time between the end of the intervention period and the follow-up.

Use of assistive technology after interventions

To have control over fidelity aspects, the teachers were given instructions regarding what the students should do between T2 and T3 for remedial teaching. The intervention group was instructed to continue using tablets with apps for their own needs and wishes, that is, the students decided how to use the app in schoolwork. In addition, the students received the support deemed appropriate by the special education teacher, that is, the same treatment that they had before the intervention period. The control group students were to receive the same support that they received throughout the investigation, that is, treatment as usual. Of course, we could not forbid them from using a tablet with apps, but the teacher was not supposed to encourage or systematically use the same tablet and apps that the intervention group had used.

Statistical analyses

In all analyses, grade 8 and high school results were pooled. Because of the small sample sizes in these grades and that they used exactely the same tests. Changes in test performance from T1 to T2 and from T1 to T3 were analyzed with paired t-tests, stratified on both treatment and grade. The effect of the intervention was analyzed by comparing the change in scores between the groups and presented as Cohen's d. For the comparison between performance at T1 and the 1-year follow-up at T3, where improvement is expected, we transformed the test results to Z-scores for evaluation purposes, using normative data. The changes in Z-scores were then analyzed with paired t tests. At T2, the intervention group carried out the 'Reading and listening comprehension test', and the time and correctness between reading and listening was compared using paired t tests. A composite score for the reading tests at the follow-up (T3) was created as the mean of two subscores, one for decoding and one for reading comprehension. The decoding subscore was created as the mean of the Z scores for word chains, non-word reading, and sight-word reading. Similarly, a subscore for reading comprehension was created by combining 'Which picture is correct? [Vilken bild är rätt]' and 'IEA' in grades 4 and in grade 8/high school by combining 'The job crisis is a scam [Jobbkrisen är en bluff]' and 'Sentence sequences [Meningssekvenser]'. Each 'project question' for students was related to the composite score of the reading tests by using Pearson's r. The kappa statistic was used to analyze the agreement between students and their parents after the ordinal scale was dichotomized into positive and negative responses.

Results

The first aim was to examine possible differences between the intervention group and the control group and compare the students' development to an age-matched norm group. In grade four, there was a significant difference in most of the tests between the two test occasions (T1 and T2) except for the sentence chain, RAN test and the spoken vocabulary test in the intervention group. In the control group, it was only the sentence chains and the arithmetic tests that were not significant between T1 and T2 (see Table 4). The only test that had a significant difference in effect size was the listening comprehension test were the

Table 5. Mean and SD on each test at T1 and T2 for the intervention group and for the control group in grade 8 and high school.

	Control ($n = 18$)			Intervention ($n = 24$)			Intervention vs control	
Test	T1 mean ± SD	T2 mean ± SD	Change *p*	T1 mean ± SD	T2 mean ± SD	Change *p*	Effect size Cohen's *d*	*p*
Word chains	20.5 ± 7.1	23.3 ± 6.1	.01	22.2 ± 4.8	23.9 ± 5.8	.05	−0.19	.38
Sentence chains	21.6 ± 8.1	24.1 ± 8.1	.23	23.9 ± 6.4	26.5 ± 7.7	.02	0.02	.94
Non-word reading	66.8 ± 18.8	74.1 ± 16.9	.05	68.8 ± 16.2	76.0 ± 18.2	<.001	0.00	.98
Sight word reading	125.0 ± 21.9	130.3 ± 22.1	.10	125.3 ± 16.6	132.0 ± 19.5	.01	0.07	.71
Orthograhpic choice	45.8 ± 20.2	55.8 ± 24.2	<.001	48.9 ± 12.7	58.2 ± 23.5	.01	−0.03	.87
RAN	32.4 ± 4.4	29.6 ± 5.1	.02	34.7 ± 6.9	32.6 ± 6.3	.01	0.13	.54
Nonword repetition	13.3 ± 2.1	13.4 ± 2.6	.77	13.1 ± 2.1	14.0 ± 1.8	.05	0.33	.20
Arithmetic	19.1 ± 5.2	20.3 ± 6.8	.25	20.4 ± 9.4	21.0 ± 10.2	.63	−0.07	.72
Written words	20.4 ± 2.5	21.1 ± 2.9	.45	20.6 ± 2.9	21.1 ± 2.7	.50	−0.06	.87
Sentence sequence	13.7 ± 2.3	14.2 ± 2.6	.43	13.8 ± 2.1	14.5 ± 2.6	.15	0.08	.78
Vocabulary	16.2 ± 2.5	18.4 ± 1.7	.01	16.4 ± 4.0	17.0 ± 4.3	.39	−0.46	.13
Woodcock Listening	23.7 ± 4.0	25.0 ± 3.4	.09	23.3 ± 3.7	25.5 ± 2.8	<.001	0.28	.37

Effect size, Cohen's *d*, is presented regarding differences in gains between the groups on the tests.

Table 6. Mean and SD on each test at T1 and T3 for the intervention group and for the control group at grade 4.

	TAU ($n = 35$)			Intervention ($n = 38$)			Intervention vs TAU	
Test	T1 mean ± sd	T3 mean ± sd	Change *p*	T1 mean ± sd	T3 mean ± sd	Change *p*	Effect size Cohen's *d*	*p*
Word chains	8.5 ± 4.7	12.1 ± 5.2	<.001	6.8 ± 3.3	10.0 ± 4.3	<.001	−0.08	.69
Sentence chains	10.9 ± 5.5	15.3 ± 7.4	<.001	8.2 ± 5.0	13.5 ± 5.6	<.001	0.14	.45
Non-word reading	46.1 ± 13.5	55.9 ± 17.3	<.001	40.2 ± 11.8	50.0 ± 13.6	<.001	0.00	.99
Sight word reading	79.1 ± 22.9	100.9 ± 26.2	<.001	73.7 ± 21.3	95.3 ± 24.0	<.001	−0.01	.95
Orthograhpic choice	16.5 ± 6.9	28.2 ± 15.2	<.001	14.1 ± 7.6	24.3 ± 8.8	<.001	−0.12	.55
RAN	45.1 ± 7.6	38.8 ± 8.2	<.001	46.2 ± 12.5	38.5 ± 9.8	<.001	−0.16	.33
Nonword repetition	11.8 ± 2.5	13.4 ± 2.3	<.001	11.2 ± 3.7	13.1 ± 2.5	<.001	0.14	.58
Arithmetic	12.0 ± 5.9	15.2 ± 5.9	<.001	9.3 ± 6.2	13.3 ± 6.3	<.001	0.12	.51
Correct picture	13.9 ± 4.7	19.8 ± 5.9	<.001	12.1 ± 4.1	17.3 ± 4.2	<.001	−0.14	.34
IEA	6.4 ± 3.2	7.5 ± 2.6	.08	5.6 ± 3.6	8.1 ± 2.1	<.001	0.58	.18
Vocabulary	13.8 ± 3.3	15.8 ± 2.8	<.001	14.7 ± 4.1	16.4 ± 3.0	.01	−0.12	.68
Woodcock listening	18.4 ± 4.0	23.4 ± 4.3	<.001	19.2 ± 4.1	22.6 ± 4.5	<.001	−0.37	.02

Effect size, Cohen's *d*, is presented regarding differences in gains between the groups on the tests at T3.

Table 7. Mean and SD on each test at T1 and T3 for the intervention group and for the control group at grade 8 and high school.

	Control ($n = 14$)			Intervention ($n = 17$)			Intervent vs control	
Tests	T1 mean ± sd	T3 mean ± sd	Change *p*	T1 mean ± sd	T3 mean ± sd	Change *p*	Effect size Cohen's *d*	p
Word recognition	20.6 ± 7.4	23.1 ± 6.9	.13	23.1 ± 4.8	24.5 ± 5.9	.24	−0.16	.60
Sentence change	22.5 ± 8.7	28.6 ± 9.7	<.001	24.4 ± 5.5	28.4 ± 7.3	<.001	−0.26	.28
Non-word reading	64.3 ± 19.0	81.8 ± 34.1	.01	65.4 ± 13.4	72.7 ± 13.5	.01	−0.41	.09
Sight-word reading	125.6 ± 21.1	131.4 ± 19.8	.38	121.5 ± 13.8	135.8 ± 19.8	<.001	0.43	.22
Orthographic choice	41.4 ± 18.3	53.7 ± 19.8	<.001	48.8 ± 10.3	67.1 ± 20.3	<.001	0.30	.28
RAN	32.0 ± 4.4	29.2 ± 4.7	.09	35.3 ± 6.4	33.0 ± 5.3	.05	0.11	.77
Nonword repetition	13.1 ± 2.2	13.6 ± 2.9	.31	12.6 ± 2.2	13.5 ± 2.7	.10	0.13	.59
Arithmetic	18.6 ± 5.9	20.0 ± 7.0	.19	19.5 ± 9.9	23.6 ± 11.4	.02	0.29	.16
Written words	20.5 ± 2.4	21.4 ± 3.1	.40	20.2 ± 2.5	20.8 ± 2.8	.36	−0.09	.82
Sentence sequences	14.2 ± 1.7	15.7 ± 1.8	.06	14.3 ± 2.2	15.0 ± 2.0	.21	−0.40	.40
Vocabulary	16.3 ± 2.7	16.9 ± 2.7	.60	16.4 ± 4.3	17.3 ± 3.2	.44	0.12	.83
Woodcook Listening	24.3 ± 3.7	26.4 ± 2.9	.08	23.5 ± 2.5	25.6 ± 3.6	.04	0.00	.99

Effect size, Cohen's *d*, is presented regarding differences in gains between the groups on the tests at T3.

control group had a larger gain (<0.05) between the test occasions. The change between T1 and T2 on the reading tests corresponded to effects between *d* 0.25 and *d* 0.71 ($M = 0.42$) for the intervention group in grade four.

In grade 8 and high school, with approximately half the number of participants compared to grade 4, non-word reading, orthographic decoding, and spoken vocabulary were significant in the control group between T1 and T2. In the intervention group, all were significant (<0.05–0.001) except arithmetic, sentence sequence, spoken vocabulary, and written words. None of the tests had a significant difference in effect size between the groups (Table 5). The change between T1 and T2 on the reading tests corresponded to effects between *d* 0.14 and *d* 0.77 ($M = 0.36$) for the intervention group in grade 8 and high school.

Results at follow-up

At the follow-up, both groups in grade 4 had gained on all tests except for reading comprehension in the control group (Table 6). Effect size did not differ significantly between groups except for listening comprehension; the control group had significantly increased ability (<0.05) compared to the intervention group.

Students in grade 8 and high school had gained on all tests, but not significantly on all of them (Table 7). Scores on five tests

Table 8. The differences in *Z*-score between T1 and T3 for grade four students.

	TAU ($n = 35$)			Intervention ($n = 38$)		
test	T1 mean ± sd	T3 mean ± sd	Change p	T1 mean ± sd	T3 mean ± sd	Change p
Word chains	−1.7 ± 0.9	−1.6 ± 0.9	.49	−2.0 ± 0.6	−2.0 ± 0.8	.69
Sentence chain	−1.5 ± 0.6	−1.5 ± 0.9	.61	−1.9 ± 0.6	−1.7 ± 0.7	.14
Non-word reading	−1.0 ± 0.7	−1.1 ± 0.9	.23	−1.3 ± 0.6	−1.4 ± 0.7	.35
Sight word reading	−1.7 ± 1.0	−1.5 ± 1.1	.03	−2.0 ± 0.9	−1.7 ± 1.0	.01
Correct picture	−1.1 ± 0.4	−1.2 ± 0.9	.61	−1.3 ± 0.4	−1.4 ± 0.5	.11
Vocabulary	−1.2 ± 0.8	−0.8 ± 0.6	.03	−0.9 ± 0.9	−0.7 ± 0.7	.06

Z scores calculated using means and SD from norm groups at corresponding ages.

Table 9. Mean, SD and *p* values for the reading and listening comprehension test for grade four, eight and high school.

Grade		Reading mean ± sd	Listening mean ± sd	p
4	Time (seconds)	156 ± 88	74 ± 23	<.001
($n = 25$)	Comprehension	3.1 ± 1.3	2.7 ± 1.3	.07
8 and High school	Time (seconds)	73 ± 22	63 ± 17	.15
($n = 9$)	Comprehension	3.3 ± 1.3	3.2 ± 1.3	.40

were significantly better at the follow-up. For the control group, results for sentence chains (<0.001) and orthographic spelling (<0.001) were significantly better at the follow-up. For the intervention group, sentence chain (<0.001), sight-word reading (<0.001), and orthographic spelling (<0.001) were significantly better at follow-up. Gains between the groups did not differ significantly on any of the tests at the follow-up.

Six of the tests used for grade 4 students involved norms. The *Z*-scores presented in Table 8 show how the participants compared to norm groups on the different tests. Both groups fell clearly below the mean on all six tests when compared to an age-matched norm group before and after the intervention. However, both groups increased ability, during 1 year, as much as the norm groups and on some tests even more, for example, in vocabulary and sight-word reading. In other words, on these tests, the gap decreased between typical readers and the participants in the present study. This calculation was not made for grade 8 and high school because of the low *n* and the lack of available norms for these age groups.

A second aim was to investigate the ability to assimilate and communicate text after the intervention. The students in the intervention group carried out the reading and listening comprehension test at T2, as a way to measure text assimilation ability. In grade 4, the paired sample t-test showed a significant difference in time ($p < .001$), with the students ($n = 26$) listening to the text faster than the time it took to read it. However, there were no significant differences in how the students comprehended the 10 questions (Table 9). In grade 8 and high school, there was a clear difference in time with the students listening to the text faster than reading it. However, the differences were not significant. There also was no significant difference between scores on the comprehension part of the tests.

The gain from T1 to T2 as well as from T1 to T3 was also compared with respect to sex. No difference was found (data not shown).

A third aim was to explore how the participants and their parents perceived the extent to which the tablet with apps motivated literacy and schoolwork at large. At the follow-up, the students and their parents were asked 11 and 10 questions, respectively, about how the interventions had affected their use of tablets and apps and their motivation for schoolwork. The questions contained five options. Table 10 shows by percentage

Table 10. Children's and parent's view of the project and the correlation between the children's view and the composite score.

Question	Child ($n = 42$) Positive %	Parent ($n = 32$) Positive %	Agreement ($n = 30$) kappa	Agreement p	Correlation to Composite score r	Correlation to Composite score p
Current usage	55	72	0.48	.01	−0.41	.01
Previous usage	65	59	0.63	<.001	−0.34	.03
Reading better	66	69	0.52	.01	−0.06	.73
More motivated	55	44	0.39	.03	−0.32	.04
More independent	42	37	0.33	.09	−0.37	.02
Following the teaching	52	52	0.38	.06	−0.24	.14
Apps as support	65	71	0.58	<.001	−0.15	.35
Assimilate text as others	71	50	0.16	.30	0.34	.03
Communicate text as others	73	59	0.24	.18	0.27	.09
Assimilate more text	61	69	0.15	.34	−0.13	.41
Apps as support in school	50				−0.40	.01

how many of the students in the experimental group and their parents answered the questions positively. Among the students, between 55% and 65% answered that they continued to regularly use the apps that were included at the follow-up during the intervention period. Fifty percent felt that using the apps in their schoolwork benefited them clearly. Approximately 40% to 55% answered that they were more independent and motivated for schoolwork after participating in the study. Almost half (47%) of the students perceived that they could better follow the teaching after the intervention, and 60% answered that the reading apps were good for listening to and assimilating texts. In addition, 60% felt that they could assimilate more text than before participating in the study.

The parents answered the same questions as their children at the follow-up except for the question about support in school. On some questions, the parent answers were almost on the same level as those of the students, for example, how the students followed the teaching and whether they had become better readers. However, on some questions, the differences were obvious, such as whether the students assimilated and communicated text as much as students without reading difficulties. The parents had lower percentages on these questions; they appeared less optimistic. To summarize, parents and children were generally in agreement. The correlation analysis shows that using the apps created more motivation and independence. It also shows that when the apps were regarded as a support for the students' overall schoolwork, they were moderately negatively correlated with the composite reading score (see 'Statistical analyses'), that is, the students with the most severe difficulties with the written language were the more positive ones.

Table 10 also shows the correlation between a composite score for reading and the questions that the students were to answer at the follow-up. For most of the questions, there was a significant correlation ($r = 0.32$–0.41) between low performers on the reading composite score and positive answers on the rest of the questions, except for "*Do you think you are reading better today compared to before joining the project?*", "*Do you follow the teaching better today when using apps?*", "*To what extent do the reading apps help you to listen and to take part of text?*", "*Do you think you can communicate text to the same extent as your classmate?*", and *Do you think you can assimilate text more now than before the interventions?*" This means that students with a low reading ability were more disposed to answer positively on questions such as, "*How often do you use the apps that were included in the project?*" and "*Are the apps a support for you in your everyday schoolwork?*"

There were four questions for the students about the usability of the tablets and the apps (see Appendix), asked directly after the intervention and at the follow-up: "*How well did it work to use the tablets?*", "*Which of the following programs did you benefit from most?*", "*What worked best with your tablet?*", and "*What worked worst with your tablet?*"

Almost all (96%) of the students responded positively to how using the tables had worked. The two programs that the students found most beneficial were 'Skolstil-2' and 'Legimus', but the 'Ruzzle' program was also highly ranked (see the 'Application' section above for a description of the apps). There were various answers to what had worked best with the tablets, ranging from very tangible answers such as, "*to scan text and get it read*", "*not having to read so much, listening instead*", and "*writing with STT*" to more comprehensive ones such as, "*everything worked well*", "*I have learned a lot*", and "*All. It has given a lot to life. It can always help me.*" The students answers to what had worked worst with the tablets often concerned technical problems and problems with a specific app, like, "*hard to get connected and to get a login, through tablet*", "*when the technology is not working*", "*technical problems with the tablet in Say Hi*", "*Prizmo was not so reliable, the text could be wrong and weird*", "*When an app has not worked*", and "*Sometimes when I talk to the STT, it got the speech wrong.*" However, this question did also lead to general answers such as, "*It takes quite a lot of energy to fix a little thing*", "*Not natural to use the tablet, no one else had it!*", and "*nothing has worked the worst.*"

There was an item for both students and parents intended to illustrate whether participation in the project affected everyday life, both at home and at school: "*Describe how participation in the project has affected you/your child?*" Most of the students who answered gave positive answers, mainly about increased skills in reading, using apps, and motivation for reading and schoolwork: "*I think I have gained a greater understanding of the importance of reading. I can focus more on the text now*", "*Increased my interest in books, better readers with Legimus*", "*It has been fun and I've become better at reading and learning*", "*It has become much better. I had not developed as much if I had not participated*", and "*positive, have learned how all apps work. Have realized that I can listen instead of reading everything.*"

The parents also gave mostly positive answers, replying that their children had become better readers, but they also reported that it affected student motivation and personality: "*She has become much better at reading*", "*Increased the desire to read printed books since audiobooks inspire. Found tools to manage his schoolwork*", "*I think it's been good. He has learned a lot and is working more on schoolwork now*", "*Happened a lot in reading. Does not need as much support in homework. No fuss about homework anymore. He thinks it's quite fun again*", "*He has become more confident as a person*", "*Good that he participated, it has helped and he has become more motivated, it has made a difference*", and "*He has become much more skilled and motivated in schoolwork, has taken a big step forward, we are very pleased.*" A few students thought it was dull, and they did not like to miss ordinary lessons.

No sex differences were found related to any of the 11 student questions (data not shown).

Discussion

The main aim of the present study was to investigate if an intervention using assistive technology for students with reading disabilities affected their reading ability, ability to assimilate text, and motivation for schoolwork. The results show gains in reading ability despite using nothing but assistive technology during the intervention period, and these gains were comparable to the enhancement in a control group during 1 year. Approximately 50% of the students and their parents reported an increase in motivation for schoolwork after they had finished the interventions.

In recent decades, several studies have emphasized the role of assistive technology for individuals with LD [see reviews by, 14,16,41,42]. This applies not least to a TTS program to improve word recognition ability, for which results have been mixed. However, most of the studies are quite old, while TTS has become much better in recent years [16]. In the present study, TTS was one of the main applications the students used in the intervention program (with three of the apps including that ability: Voice Dream Reader, Skolstil 2, and Prizmo). The results for word decoding and word-recognition were similar to those of earlier studies, that is, the students gained significantly on all the three tests measuring that ability. However, the effect in the current work was almost moderate compared to the small effect prevalent in earlier studies [16]. This difference might be the result of increasing effectiveness of TTS. The arithmetic test showed no significant gains, which might further strengthen the impact of assistive technology intervention on student decoding ability, as there was no expectation of any gains in arithmetic ability. The control group in this study received treatment as usual and gained as much as the intervention group on the three tests measuring decoding and word recognition. Actually, although both groups gained significantly on most of the included tests at the posttest (T2), at least in grade 4, the gains did not differ between the groups. At the 1-year follow-up, the students in both groups had gained significantly on all tests ($p \leq .01$ to <0.001). For the intervention group, both students and parents also reported that reading had improved from before the participation in the project (Table 9).

As for the present study's first aim, the groups did not differ on any of the reading tests after the intervention or after the follow-up (Tables 5 and 6). However, the hypothesis was that the control group would outperform the intervention group on these tests, especially on decoding tests, not least because several of the participants in the control group received specific training in decoding. This hypothesis was not confirmed. Instead, the findings in the present study underline that the intervention, with the inclusion of TTS, also had a remedial value and did not only compensate for shortcomings in word decoding, as has been found in earlier studies [12,20]. Thus, even if the students worked solely with assistive technology, they did not lose their ability but basically maintained the same pace as those who receive treatment as usual.

Furthermore, both groups had at least the same degree of enhancement as the grade-level control group on each of these three tests which might indicate that the interventions for both of the groups worked (Table 7). However, the reason for this positive increase in decoding, for the intervention group, might to some extent be that most of the students had already acquired basic skills in word decoding, even if their ability was not sufficient to catch up with the requirement of their grade level. In other words, if students have not reached an understanding of the relation between letters and sounds and how to combine them, it might be harder to improve their decoding after using TTS. It is thus necessary to have acquired basic skills in reading as a fallback. For this reason, we emphasize the importance of receiving intensive training in reading at least during the first 3 years in school [2]. If children at the beginning of grade 3 still have not reached a sufficient reading level, the results in this study and earlier studies have shown that programs like TTS can be one way not only to compensate for but also to remediate difficulties in decoding words (see Perelmutter et al. for a review) [16].

The present investigation includes three age groups, grades 4 and 8, and high school. The reason for this design was to assess possible differences in how age groups developed in reading ability and assimilating text. Previous studies have shown that younger students develop more on reading tests than older students when using assistive technology [16]. This study yielded no evidence for this, as students in grade 8 and high school developed as much as students in grade 4. However, the results are uncertain because few students, especially from high school, participated in these older age groups.

The second aim of the current work was to examine whether the intervention affected the ability to assimilate and communicate text, which is a broader concept also including listening to text and using a speech recognition program. The reading and listening tests were constructed to measure, in some sense, the way of assimilating text, in that the student had to both read and listen to a text. The difference between reading and listening to a text was obvious among the students. The listening part of the test took half the time in comparison with reading the text, but the students had still almost the same number of correct answers on the comprehension questions (referring to students in grade 4). There were also questions raising this topic, and more than 70% answered positively, reporting that they had become better at assimilating and communicating text after the intervention (Table 9). The parents also answered these questions, but their answers were less positive (~60%). However, although the reading and listening test measured differences in time between listening and reading a text, it is uncertain that the test evaluated whether the student had actually assimilated more text than before the intervention.

Our intention was also to include tests investigating the ability to communicate text, as noted, but none of these tests truly captured this ability. Thus, it was not possible to obtain an appropriate picture of text communication, even though 59% to 73% of the parents and students answered after the intervention that they were as good at communicating texts as their classmates who were without reading and writing disabilities. Consequently, these concepts were not easy to measure, either through tests or questions to the students and their parents. Edyburn [8] drew the same conclusion that instruments are lacking that are good enough to measure both short and the long-term effect of using assistive technology. More research on this issue is thus necessary.

The third aim was to analyze how the students enjoyed the tablets with apps and whether the intervention affected their motivation for literacy and schoolwork in general. For a better understanding of this issue, supplementary questions were put to the participants in the present investigation and their parents. The most appreciated apps were Skolstil 2, Legimus, and Ruzzle. These apps compensate for the most basic reading functions and might also train the ability to some extent, for example, by listening to the relation between letter and sound that builds a word (Skolstil 2), practicing the ability to find words among a string of letters (Ruzzle), and listening to facts and fictional texts (Legimus). The intention behind using the Ruzzle game was to maintain motivation. This app was one of the most appreciated, and because the students' task in the game is to find words from a string of letters, it might also have trained their ability in decoding words.

The other apps were also appreciated but not as much as these three. Even if almost all students were positive about using the apps during the intervention, ~35% did not use them at the follow-up. Several comments emerged regarding technical problems and apps that did not work as they were meant. For example, the app that scanned text (Prizmo) and STT caused a few user problems, such as text that sometimes was not scanned satisfactorily and was therefore impossible to listen to, or that the STT app did not always recognize speech well enough. These apps are very dependent on good lighting conditions, clear speech, and surroundings that are not too noisy. However, as time have passed since this project started, they have improved and would probably be even more appreciated today [14].

Other explanations for why some students did not use assistive technology 1 year after the intervention were that teachers did not inform each other about their students' participation in a project. These students were therefore not encouraged to use assistive technology in all of their regular school subjects. In some schools, there was no access to tablets or time to motivate students to continue using the equipment after the intervention period. Nevertheless, 65% of the students still used the tablets with apps. This result can be considered as supporting the evidence that assistive technology, in this case a tablet and accompanying apps, works well in educational contexts in general, especially for students with severe reading and writing difficulties.

Earlier assistive technology studies have called for more research concerning how this technology affects people's lived experience and motivation for schoolwork [14,16,43]. One of the aims in the present study was to evaluate both the usability of assistive technology and its motivational aspect in a school setting parallel to analyzing effects on reading development. In the present study, 42% to 55% of students, as well as a slightly lower percentage of parents, perceived that the intervention with the use of apps had positively affected motivation and independence, and that the apps worked as a support for reading and general schoolwork. The correlation analysis (Table 9) showed that this was especially valid for students having the most severe difficulties with the written language. This result is to be expected because those with major difficulties really needed support for reading and writing to complete their schoolwork. After participating in the study, one student expressed what was best about using assistive technology: "*All. It has given a lot to life. It can always help me.*" However, a few students thought that they stood out by their use of a tablet when other classmates did not have one, which is a fairly important aspect. Even in the preceding pilot study [12], some students felt the same way.

In the overview by Haßle et al. [14], the authors claim that studies have to extend over at least one academic year to give a more comprehensive picture of the educational benefit of using a tablet. We fully agree. This study lasted for one academic year only, and it may be necessary to choose an even longer period to study the ability to assimilate and communicate text. A longitudinal perspective may lead to a deeper understanding of whether using assistive technology with apps is as good as reading and writing in a traditional way. Some results in this study provide evidence that assistive technologies can compensate for written language difficulties as well as improve the ability to decode text in the traditional way. What is perhaps even more important is that approximately half of the students in the present investigation did increase their motivation for accessing text and schoolwork in general. The assistive technology available today for students with reading and writing difficulties is sufficiently good to represent a real alternative at least for those with severe difficulties in these areas. At the same time, the use of this technique needs to become more generally accepted in society and especially in the school environment. Assistive technology is useful for all students, but for those with a disability, it is a necessity. In this article, the concepts of assimilating and communicating text are used to obtain a broader view.

Reading and writing are associated with following a traditional procedure, while assimilating and communicating text expands the possibilities, which represents a more contemporary view. Consequently, the way it works is not as important as giving everyone the best opportunity to understand the content of different types of information, such as factual and fictional texts, as well as enabling all students to express themselves. It is possible that within a not-too-distant future, there will be at least two options: either to read and write or to use technology to assimilate and communicate text, which will apply to all citizens regardless of whether they have difficulties with the written language.

Nevertheless, according to the most recent review articles, it is essential that studies include both quantitative and qualitative aspects and the relationship between them [14,16]. Thus, further research is needed, especially regarding lived experience and the use of assistive technology for students who have difficulties with written language.

Limitations

Because of the strict cutoff level in the present investigation, a great many schools ($N = 60$) and teachers ($N = 70$) were involved to ensure recruitment of a reasonable number of students. Although every teacher was trained in both tests and interventions and there was a joint webpage, it turned out to be difficult to collect all the data, not least at the follow-up. For example, several teachers forgot to collect data from some instruments, which were not retrievable at a later stage. It therefore became difficult to acquire more accurate information about the control group and the treatment as usual they performed while the trial group went through their interventions. The teachers in the control group described what the students did, but most of them omitted noting the time of the sessions. One reason was that, unlike the experimental group, the control students did not have a specific teacher who followed them daily during the intervention period. Such difficulties in collecting data, especially at the follow-up, have been reported in earlier studies (see Perelmutter et al. [16]). However, the students in the control group enhanced their reading ability as much as a norm group which might indicate that TAU was effective. Another limitation was that it became challenging to measure assimilating and especially communicating text. One reason is that the research field is quite novel regarding measuring these abilities and more research is needed for the construction of assistive technology instruments. This have also been highlighted in earlier publications (see Edyburn for a review) [14].

Conclusion

This study had three main purposes: to investigate whether assistive technology affects traditional reading ability, whether it improves student ability to assimilate and communicate text in a longer perspective, and whether it influences their motivation for schoolwork in general and reading in particular. Several previous studies have shown that students using assistive technology such as TTS enhance their decoding ability even if they do not specifically practice this skill. This study yielded similar findings. Furthermore, students increased as much as the control group receiving 'treatment as usual' and in comparisons with an age-matched norm group. The results that indicated their improvement in reading also were confirmed by both the students and their parents. The results of the second aim, to investigate if they became better at assimilating and communicating texts, were not as unambiguous. The tests used for this aim did not fully capture what they were expected to measure. However, both test results and student and parent self-estimates showed that the students did become better at managing the technology quickly and at listening easily to a text and thus increasing the ability to absorb text. Nevertheless, more research is required to find reliable quantitative as well as qualitative instruments for investigating whether assimilating and communicating text via assistive technology actually increases written language ability among students with reading and writing disability compared to traditional approaches. Several studies have highlighted the importance of motivation in schoolwork, not least for students with difficulties in reading and writing. With regard to the third aim, the intervention of assistive technology contributed significantly to motivation for both reading and schoolwork in general. Several students felt safer at handling schoolwork, as confirmed by their parents. Some of the students offered the insight that by listening to a text, they understood the content better and that this way of 'reading a text' was accepted as well by both students and teachers.

Finally, what does this study offer for filling the gap that persists in the area of assistive technology and difficulties in the written language? Assistive technology is not only a tool to compensate for a disability but also can promote reading skill development. Earlier studies that have investigated the benefits of using assistive technology mostly focused on the effects concerning decoding and reading comprehension. The novelty of the present study was that we incorporated the concepts of assimilating and communicating text, which is the main purpose of reading and writing. Thus, to assimilate and communicate text on equal terms.

According to student self-reports, assistive technology seems to work out best for students with the most severe difficulties in written language. When using assistive technology, the motivation for reading/listening to text increased and the motivation for schoolwork in general increased too. Several students in the present study realized the benefit of having access to assistive technology in everyday schoolwork. However, a great deal remains to be learned and more research is needed, especially to attain deeper insight into the long-term usefulness of assistive technology for students with reading and writing disabilities.

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Appendix

Complete list of questions

How often do you use the apps that were part of the project?
How often did you use the apps that were part of past year's project? (on average)
Do you think that your reading is better today than before you joined the project?
Has your motivation for schoolwork increased after working with the reading apps?
Do you experience yourself as more independent in school work after you have practiced with the reading apps?
Do you think that you follow the teaching better if you use the reading apps?
To what extent do the reading apps help you to listen to/take part of texts?
Do you feel that you are as good as your classmates at understanding text?
Do you feel that you are as good as your classmates at communicating text?
Are you consuming more text than before?
Are the apps a support for your schoolwork today?
How well did it work to use the tablets?
Which of the following programs did you benefit from most?
What worked best with your tablet?
What worked worst with your tablet?